ICANS-XIX
19th Meeting of the International Collaboration on Advanced Neutron Sources
March 8-12, 2010
Grindelwald, Switzerland

# SHIELDING DESIGN FOR CSNS TARGET STATION

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ABSTRACT

Shielding calculations for Chinese Spallation Neutron Source (CSNS) target station have been performed with MCNPX and DOORS simulation codes. A new general purpose neutron and photon data library, for neutron energy up to 150MeV, and for photon the energy up to 100MeV is generated for 30 nuclides. It contains 81 high-energy and 172 low-energy neutron groups and 48 photon groups. The library is used with DORT for shielding design. Because the lowest inelastic energy level of $^{56}Fe$ is 847keV, there is a buildup of neutrons below this energy. Thus a thin concrete layer in the steel like a sandwich structure is effective to reduce neutron dose rate. High Intensity Powder Diffractometer is one of the three instruments that will be built during day one in CSNS project. We give the primary shielding design for this beam line including the choice of shielding material and the shielding thickness.

## 1. Introduction

The Chinese Spallation Neutron Source (CSNS) project is a 100kW-level spallation neutron source in its day one and now is under progress of the close cooperation between Institute of Physics (IOP) and Institute of High Energy Physics (IHEP)[1,2].

When the proton beam bombarded the tungsten target, the energies of the cascade neutrons may approach the energies of the incident protons. These high-energy neutrons are extremely penetrating, and well-designed shielding is needed to prevent them from causing excessive biological dose rates. It is important that structural shielding be properly designed and installed in the original construction because correction or additions, after facilities are completed, are usually expensive.

In this paper, we have performed the shielding design for CSNS target station based on the two different methods MCNPX [3] and DOORS [4]. Besides HILO2K [5], we use a new neutron and photon data library with DORT for shielding design. We find that adding a thin concrete layer in the steel is more efficient to shield neutron dose rate than the whole steel. High Intensity Powder Diffractometer is one of the three instruments that will be built during day one in CSNS project. We also give the primary shielding design for this beam line.

## 2. The neutron source term

To provide a basis for the shield design, we give the distribution of high-energy neutron (En>20MeV) around the bare tungsten target when the target is bombarded by 1.6GeV proton (see Fig.1). Figure 1 shows the neutrons around the target are relatively hard especially in the forward direction which will approach the energy of the inject proton.

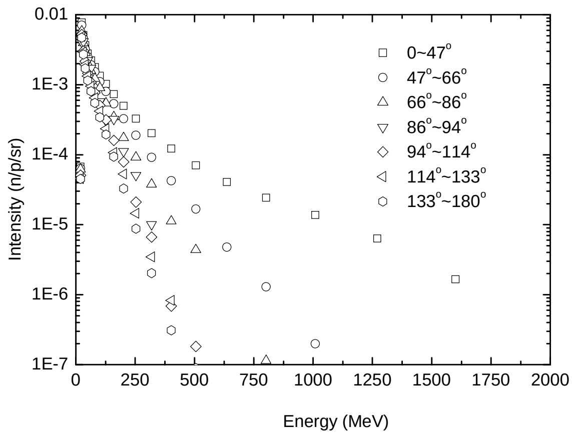
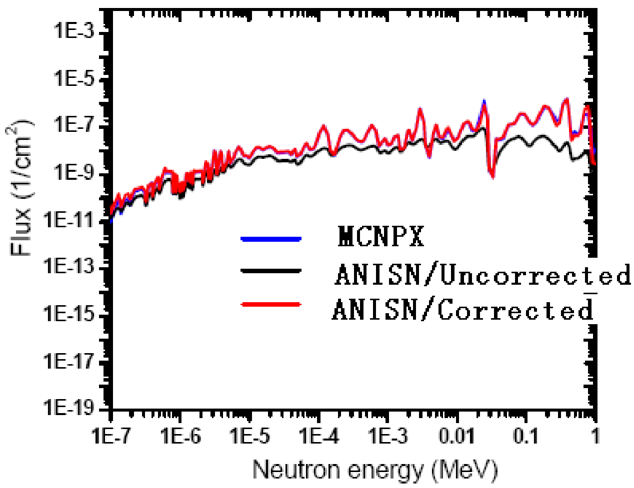


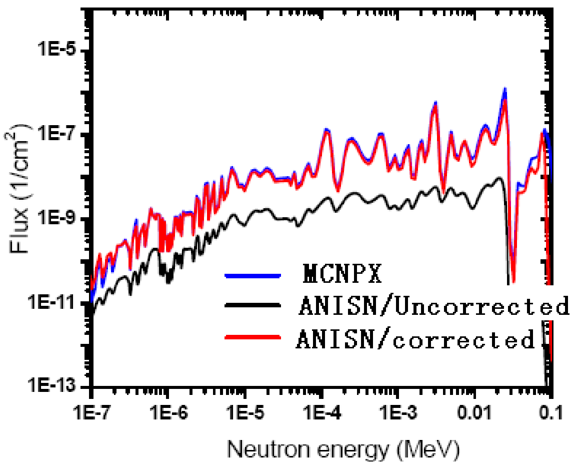

Figure1 the high energy neutron spectra around the target in the different directions (here $0^o$ means the proton beam incident direction)

## 3. The Monte-Carlo simulation and discrete ordinates methods

The Monte Carlo particle transport code MCNPX with a variety of variance reduction techniques is very suited for shielding design especially for analysing geometrical complex system. For the simplified 2-D CSNS target station shielding design, we also use the deterministic discrete ordinates transport code DOORS. We had performed a simple test calculation to compare these two codes: MCNPX and DOORS/HILO2K [6]. In this paper all of these DOORS calculations use the newly developed cross-section library HEST1.0 [7]. The library contains 301 total energy groups, 81 high-energy neutron, 172 low-energy neutron and 48 photon groups. For iron or low-carbon steel as in our case, the coarse group structure below 20MeV will cause sharp dips in the neutron spectrum corresponding to each resonance region. In order to obtain reliable results a corrected cross section is implemented in HEST1.0 for iron of natural isotopic composition. Figure 2 gives the comparison between MCNPX and one-dimensional discrete ordinates neutron/photon transport code ANISN in DOORS with the uncorrected and corrected cross sections. The model of this calculation consists of a steel sphere of 1 meter in radius with an isotropic 1 or 0.1MeV neutron source in the center. We find ANISN with the corrected iron cross section give the results that agree with the results by MCNPX very well.




(a)




(b)

Figure2 the neutron fluxes at the outer edge of the 1-meter steel sphere calculated by MCNPX, ANISN/uncorrected cross section and ANISN/corrected cross section

## 4. The primary shielding design with DORT for CSNS TS

We had performed the primary shielding design for CSNS target station (CSNS TS) with Monte Carlo codes LAHET/MCNP4C, NMTC/JAM [2]. Here we give another calculation based on DORT, where the neutron source term is supplied by MCNPX calculation. Figure 3 is the flow chart of this calculation sequence. To mitigate ray effects, GRTUNCL [4] is used to calculate the uncollided flux and the first scattering source throughout the model. Then two-dimensional discrete ordinates neutron/photon transport code DORT in DOORS using the first scattering source completes the transport calculation.

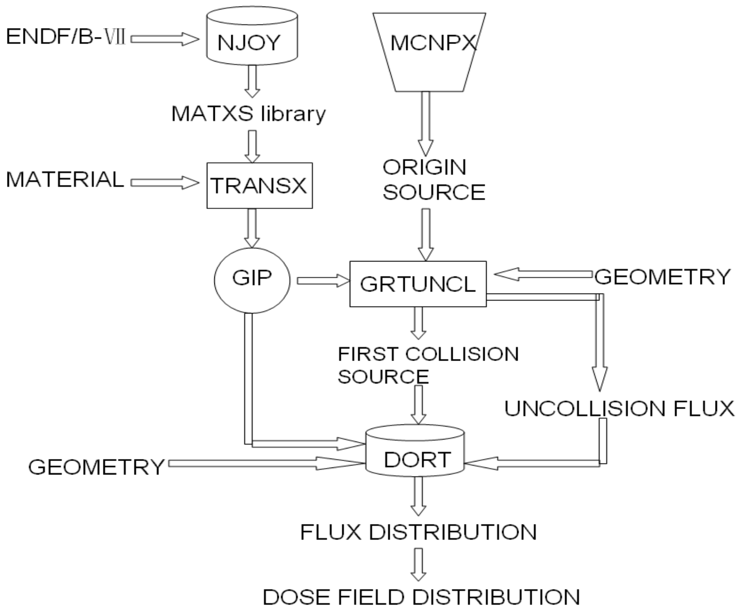



Figure 3 calculation flow diagrams for shielding analyses

Figure 4 is the 2-D calculation model. The target station monolith is cylindrical in shape with the target located at the center of the monolith and 200 cm above the bottom. The shutters are positioned on each neutron beam line approximately 250 cm from the center. For simplifying, the TMR only consists of a tungsten target, a beryllium surrounded by stainless steel reflector.

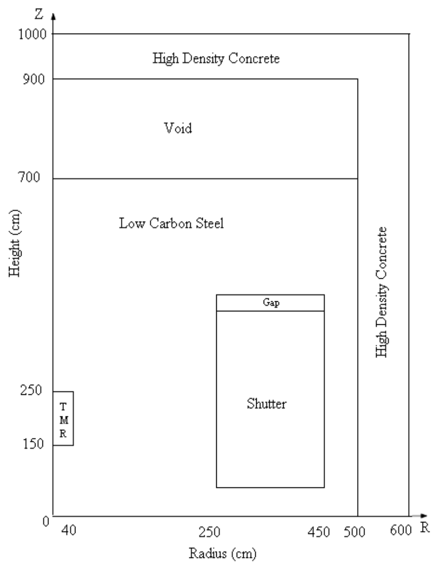



Figure 4 CSNS TS monolith model

MCNPX calculates the neutron spectrum escaping from the reflector surface (see Fig.5) as the source term. Figure 6 gives the DORT results and it shows five meter thick steel adding 1 meter thick heavy concrete is enough for shielding 100 kW target station. This result basically agrees with that based on the Monte Carlo method.[2]

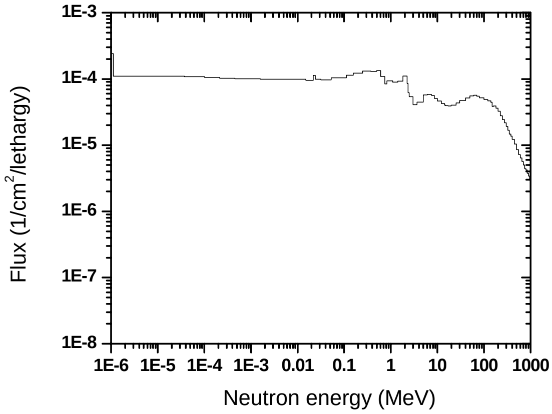



Figure 5 the neutrons leaking spectrum from the reflector cylindrical surface

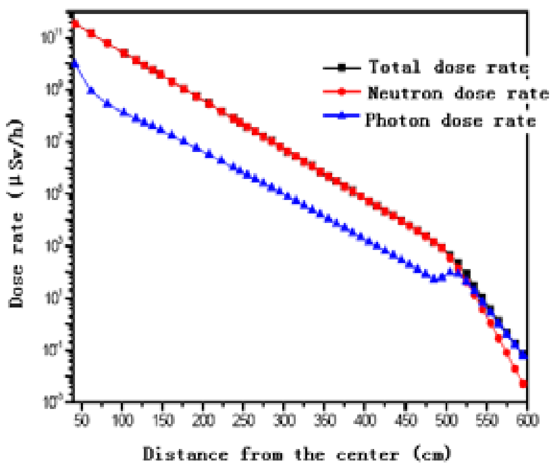



Figure 6 the dose rate with the distance from the center

## 5. The sandwich structure of the CSNS TS

A relative high density in conjunction with low cost and economical attraction makes steel an attractive shielding material. However, $^{56}Fe$ ( iron is 91.7 percent $^{56}Fe$ ) has an important deficiency in shielding neutrons that its main property is to slow down neutron with energy above 847 keV via inelastic scattering reactions, whilst below this threshold neutron can only lose its energy via elastic scattering, a very inefficient process[8]. Consequently, there is a buildup of neutrons below this energy. Moreover, iron has some regions where the total cross section is very low in $^{56}Fe$ ：at 24.5keV where the minimum cross section is below 0.01barn and at 73.0keV where the minimum cross section is below 0.1barn (see the data from ENDF/B-VII.0). The effect makes the attenuation length much longer than the high-energy attenuation length. In the target shielding design, we had considered a sandwich structure to compensate this deficiency. Figure 7 is the MCNPX geometrical model. We add two concrete layers in the steel bulk shielding. One is located above the target centre 250cm with its thickness 30cm; the other is located above the centre 475cm with its thickness 25cm. Our previous results show that this sandwich structure is much more efficient to shield neutrons and gamma dose rate than the integrated steel.[6] Here we give the neutron and gamma currents escaping from surface 113,114,117,118, and 119 to show this structure that the concrete (or other hydrogenated material) is backed the steel in the different position absorbs the surviving lower energy neutrons which do decrease the dose rate sharply (see figure 8).

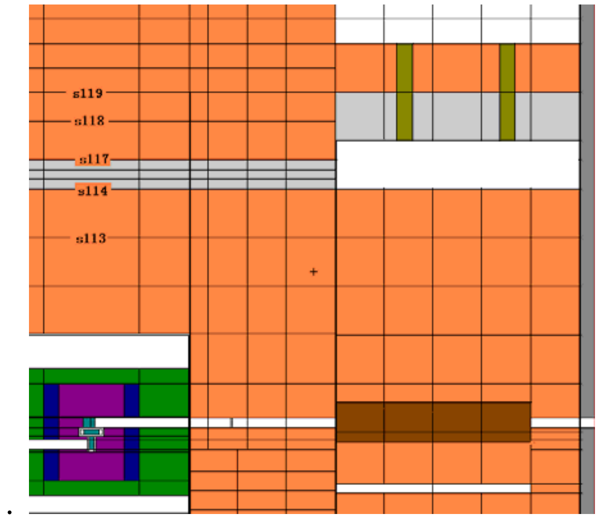
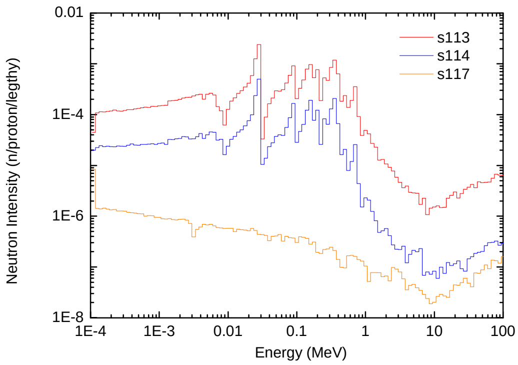
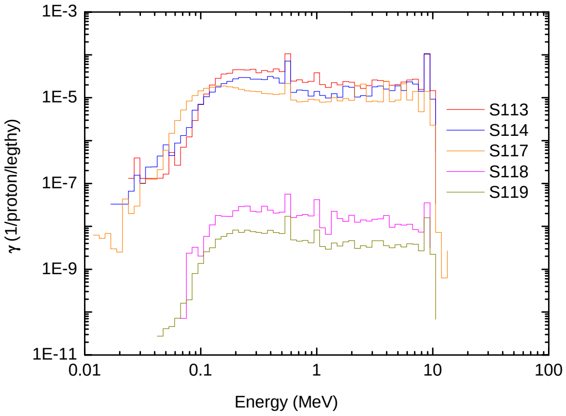



Figure 7 the MCNPX model for CSNS TS shielding



(a)




(b)

Figure 8 (a) the neutron current escaping from surface 113,114,117 and (b) the gamma current escaping from surface 113, 114, 117, 118, and 119.

## 6. HIPD beam line shielding design

High Intensity Powder Diffractometer is one of the three instruments that will be built during day one in CSNS project (see Figure.9). The beam line faces to the water moderator and is located on the direction perpendicular to the proton beam.

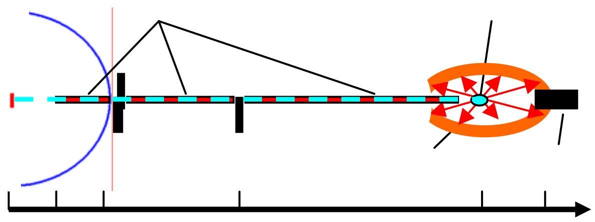
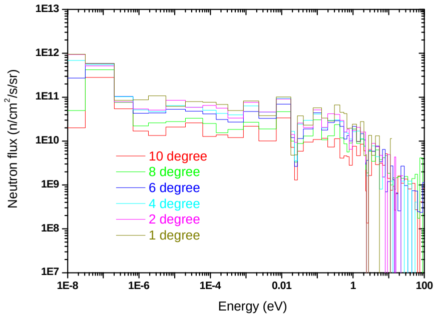
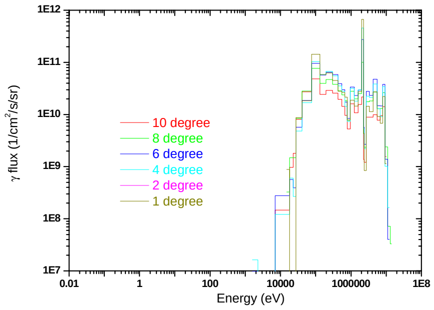


Figure 9 the sketch of the instrument HIPD of CSNS

We consider neutrons and gammas that escape from the water moderator and enter the core opening of 100mm×100mm, over a 2 degree cone with regard to the centreline as the source term. Two angular groups are considered: one is within cone of 0~1 degree and with 1~2 degree with regard to the nominal direction. Each of them has its own energy spectrum. The neutron and gamma spectra in the different angular groups are shown in Figure 10




(a)




(b)

Figure 10 the neutron and gamma spectra in the different angular groups entering the core opening of 100mm×100mm

Here we focus on the material for the neutron beam line shielding. In ISIS-TS2, a mixture of boron and paraffin wax is used for beam line shielding. Steel adding borated wax is more efficient for the neutron shielding than steel adding heavy concrete [6]. But it is more expensive and in common with all hydrogenous materials, wax presents the difficulty that thermal neutron capture in hydrogen leads to a buildup of 2.2MeV photons, which transform a neutron shielding problem to gamma shielding problem. In CSNS case, the proton energy is twice that in ISIS, then gamma rays produced by high-energy neutrons will be much higher than ISIS case. Thus we choose steel adding heavy concrete as the neutron shielding material. The composite material of 50 volume percent polythene and 50 volume percent steel with its thickness 15cm is chosen to surround the beam hole like SNS to increase the efficiency of shielding neutrons. This composite material is very efficient to decrease the neutron dose rate as the same reason like the sandwich structure mentioned above (see Figure11). The polythene absorbs the neutron with its energy below 1MeV and because the moderating property, the neutrons has a peak during 0.01~0.1eV. We had given the primary shielding design for the whole HIPD beam line [6]. As

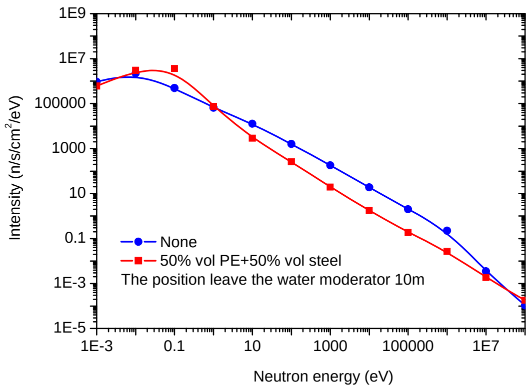



Figure 11 the neutron current escaping from the beam hole with and without the composite material

an example, we give the neutron dose rate of the section which is away from the decoupled water moderator from 10 meter to 17 meter. Figure 12 shows total shielding thickness 1.1 meter is enough for shielding neutron dose rate.

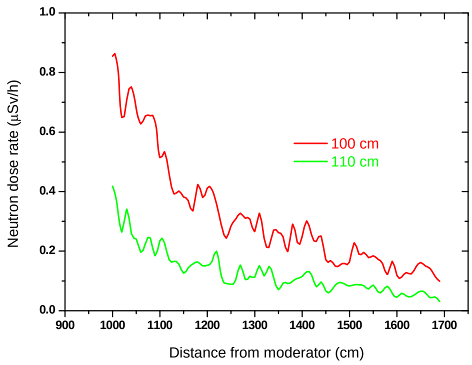



Figure 12 the neutron dose rate of some section of HIPD, which leaves the moderator from 10m to 17m.

## 7. Conclusion

We have performed the shielding design for CSNS TS with two different methods. The sandwich structure is more efficient for both neutron dose rate and gamma neutron dose rate shielding than the integrated structure. We also give the shielding design for HIPD. Here we focus on the material choose. We choose the composite material of 50 volume percent polythene and 50 volume percent steel around beam hole like SNS and steel adding heavy concrete as CSNS neutron beam line shielding material based on economical and engineering reasons.

## 8. Acknowledgement

We thank Dr.F.Gallimer and Dr.P.Ferguson, Dr.F.Maekawa for very helpful discussion in the designing CSNS TS shielding.

## 7. References

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